

Enhanced Worldwide Ocean Optics Database

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LONG-TERM GOALS

The long-term objective is to provide a comprehensive worldwide optics database that includes data on a broad range of important optical properties, including diffuse attenuation, beam attenuation, and scattering. Data from ONR-funded bio-optical cruises are given priority for loading into the database, but data from other scientific programs (NASA, NODC, NSF) and from other countries will also be routinely added to the Worldwide Ocean Optics Database (WOOD)¹. The database shall be easy to use, Internet accessible, and frequently updated with data from recent at-sea measurements. The database shall be capable of supporting a wide range of applications, such as environmental assessments, sea test planning, and Navy applications. The database shall include derived optical parameters so that if measured data are not available, the user can obtain values computed from empirical algorithms (e.g., beam attenuation estimated from diffuse attenuation and backscatter data). Uncertainty estimates will also be provided for the computed results.

OBJECTIVES

A main analysis objective has been to determine whether radiative transfer theory can be used to accurately generate “Derived Parameters.” Another objective is to provide data and algorithms having direct relevance to US Navy applications and needs. The US Navy has a special interest in locations such as the East China Sea, Yellow Sea, Gulf of Oman, and the Persian Gulf. Therefore, we will give special attention to testing the algorithms/software using data from such locations. Attention will also be given to testing the methodology within nepheloid layers (sediment-laden bottom waters) because of the US Navy’s plans to use optical sensors to detect bottom mines. An on-going objective is to acquire and add new optics data to WOOD, and therefore a related objective is to develop more automated procedures for ingesting new datasets, especially from high-density measurement systems like a glider or SeaSoar system². Finally, assuring high data quality is a major objective, so substantial effort will be given to removing noise, calibration shifts, and other data artifacts from the data.

APPROACH

With regard to the use of radiative transfer theory to generate derived parameters, we are using multi-wavelength AC-9 and HydroScat backscattering data to test software such as Kiefer’s Hydro-Optical Analysis System (HOPAS)³. Essentially one uses a version of HydroLight to “invert” easily measured optical data [such as Apparent Optical Properties (AOPs), irradiance, and radiance], to obtain estimates of Inherent Optical Properties (IOPs). Data from a variety of seasons and locations are being tested in

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order to determine seasonal and geographic dependencies. Our focus is on the empirical relationships among the IOPs known as absorption (**a**), scattering (**b**), and total beam attenuation (**c**), and on the relationship of the various IOPs to the diffuse attenuation coefficient (**K**). The accuracy of each algorithm will be assessed in terms of absolute errors, such as the root-mean-square difference between measured and calculated values, and in relative terms such as the median absolute *percent* error. The absolute error is used to treat high or low values equally. The relative (percentage) error is used to account for the great variability in attenuation coefficient values as a function of depth.

In performing this algorithm work, we are presently working with Eric Rehm, a graduate student at the University of Washington, to process Sea of Japan data provided by Dr. Greg Mitchell (Scripps). (Those data were acquired as part of a major ONR field program conducted there in March/April 2001.) If that work is successful, then we plan to use high quality military survey data from the Middle East and the Yellow Sea to further test the methodology.

WORK COMPLETED

The main thrusts of our work this past year involved 1) preparing/loading new bio-optical data into WOOD, 2) preparing and submitting a journal paper on our data thinning algorithms which are applied to over-sampled data, 3) adding software to create custom “on-the-fly” mapped statistical summaries of data, 4) adding software to quantitatively compare statistical summaries of in situ and satellite imagery data, and 5) collaborating with Eric Rehm who is running software that uses radiative transfer theory to compute derived optical properties. We also worked with another US Navy sponsor to set up a transition version of WOOD that will contain all the data in WOOD plus DoD-restricted and classified data. More detailed descriptions of these accomplishments are included in the following paragraphs.

New Data Added to WOOD: With respect to the preparation and loading of new datasets, Table 1 summarizes what has been accomplished since September 2007. In addition, the following large collections of data is presently being processed: the NASA SeaBASS⁴ data acquired since January 2000 (SeaBASS data prior to Jan 2000 are already loaded into WOOD). Figures 1 and 2 are examples of locations of new bio-optical data added to WOOD in the Western Pacific Ocean. Figures 1 and 2 also show some of the actual profiles.

Table 1. Datasets Loaded into WOOD During GFY 08 (as of 30 August 2008)

<i>Data Description</i>	<i>Example Number & Types of Profiles</i>
Rutgers “RU16” US East Coast glider data	553 “intelligently thinned” bb532, bb660, CHL_a, CDOM, Temperature, & Salinity profiles
Rutgers “RU6” US East Coast glider data	592 “intelligently thinned” bb470, bb532, bb660, bb880, CHL_a, CDOM, Temperature, & Salinity profiles
Siegel’s “Plumes and Blooms” multi-yr Program near Santa Barbara	> 5,000 profiles: Ed, Lu, Kd, a,c,bb versus wavelength, CHL_a, KPAR, PO4, Phaeophytin, rel. fluorescence, and CTD profiles of temperature and salinity
Nova University Indian Ocean/Arabian Sea	27 CTD + pigment + Kpar profiles
March 2008 Philippine Sea	3 CTD (salinity& temperature) and "K" & bb532

Sept 2003 Ryukyu Ridge	9 salinity, temperature, c532, "K" & bb from aBeta, Kd488, and CHL_a profiles
Sept 1987 NORDA Sargasso Sea	13 K490 & Temperature profiles
Sept 1996 OSU "Tow 64" SeaSoar profiles south of Cape Cod	184 AC9, relative fluorescence, & CTD data profiles
July 1994 Gulf of Mexico	178 optical backscatter (at 170 deg), diffuse attenuation coefficient, absorption, and temperature profiles
July 2001 East China Sea	Loaded 45 profiles of c(660), K532, bb532, CHL_a, and CTD profiles of Temperature and Salinity

Ryukyu Ridge Dataset of c532, K488, bb532, CHLa, T & sal

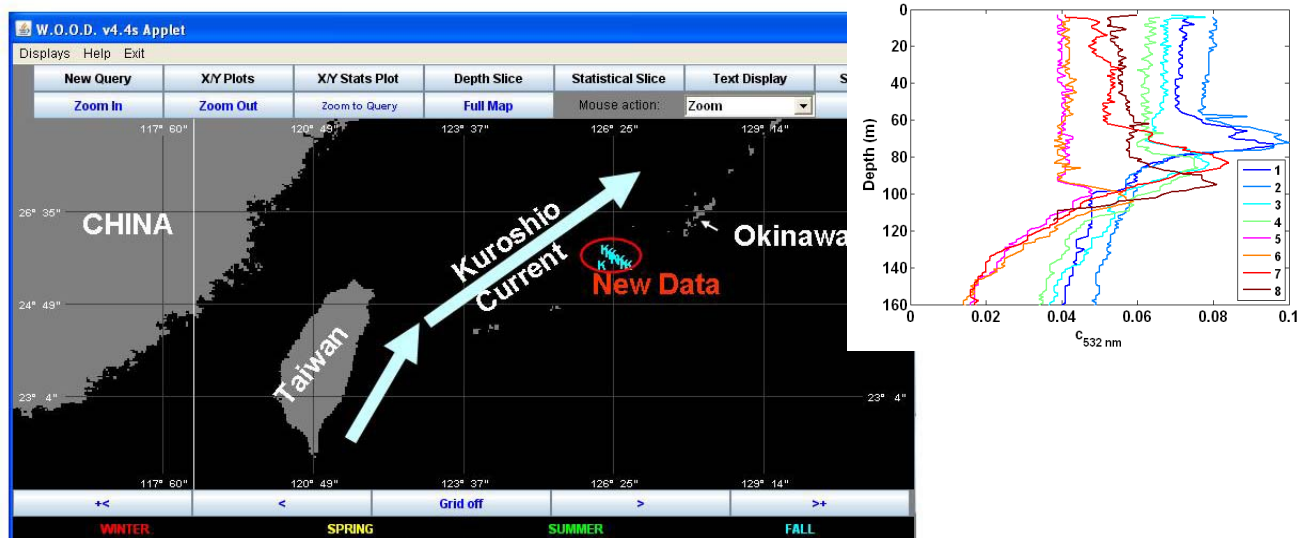


Figure 1. Map of September 2003 Ryukyu Ridge Data Added to WOOD.
[The data include c488, K488, CHL_a, and CTD profiles located southwest of Okinawa and southeast of the Kuroshio Current]

Data Thinning Software: JHU/APL data thinning software was applied to the Rutgers Slocum glider data and to the OSU SeaSoar cruise datasets. A journal paper that documents the algorithms and the software was completed and submitted for review.

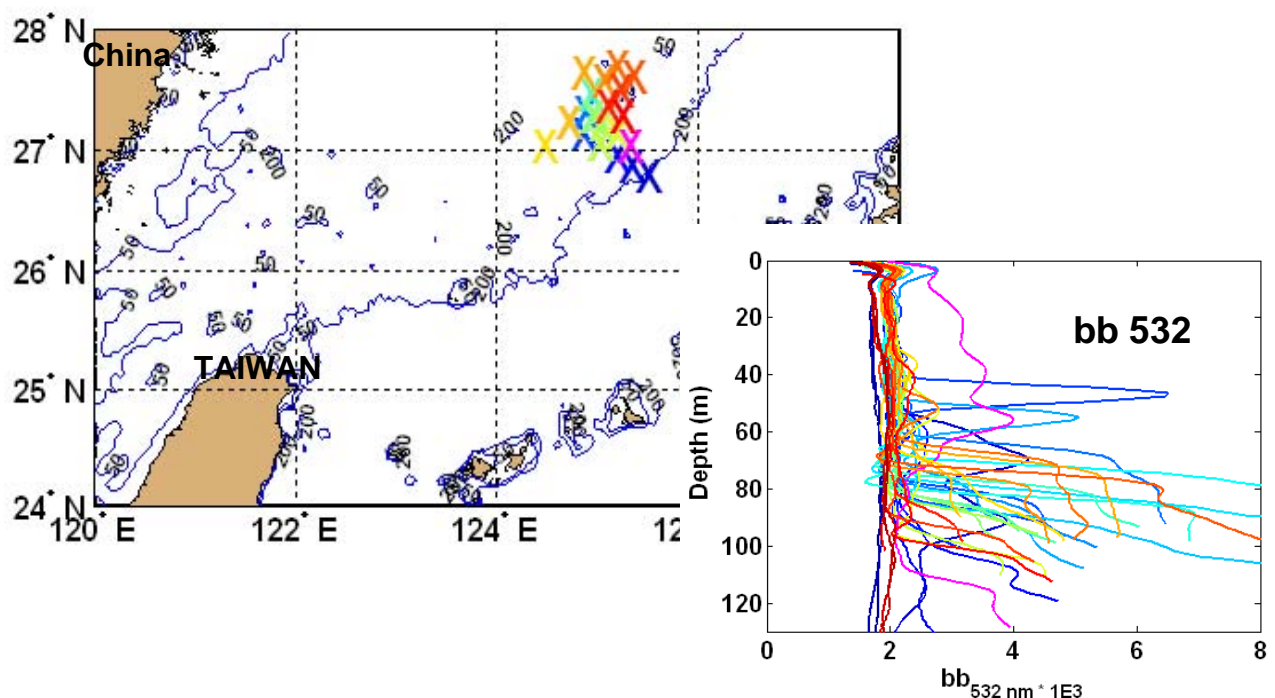


Figure 2. July 2001 East China Sea Data Added to WOOD. [Most of the profiles come from water < 200 m deep on the continental shelf northeast of Taiwan. Near-surface values of bb532 are relatively low and uniform with depth, but the values generally increase rapidly in the nepheloid layer, which encompasses the bottom 20 to 40 m of the profiles]

New Software Added to WOOD: A major new feature was developed and added to the graphical user interface (GUI): the ability to compute and display gridded statistical summaries on a map. This capability was implemented for both in situ profile data and for NASA's monthly surface climatology files of K490 from the MODIS ocean color sensor. Figure 3 shows an example of the median diffuse attenuation coefficient map created for the Western Pacific Ocean for January using the NASA multi-year average K490 data file. (The same map can be output at the 10 or 90 percentile, and the gridded data from any of these maps can also be extracted as a tabular text file.) With respect to in situ data, the statistical mapping feature is especially useful for situations where there are thousands or even tens of thousands of profiles in the user's region of interest. In such cases, making a color-coded horizontal "slice" plot through the area fails to display the characteristics of a particular site because too many data values fall on top of one another. By providing a gridded summary map, such display issues are avoided and a statically accurate representation of the region is provided.

The newest WOOD feature combines the ability to make gridded statistical summaries of either in situ or satellite data: WOOD now allows the user to compute the difference between the satellite and in situ values in each grid and output the results as a color-coded map. The associated GUI ensures that both data sources are from the same time period (e.g. a specific month) and at the same wavelength. (The GUI allows the satellite data to be converted from 490 nm to other values using Austin-Petzold's empirical relationship for $K(\lambda)$.⁵

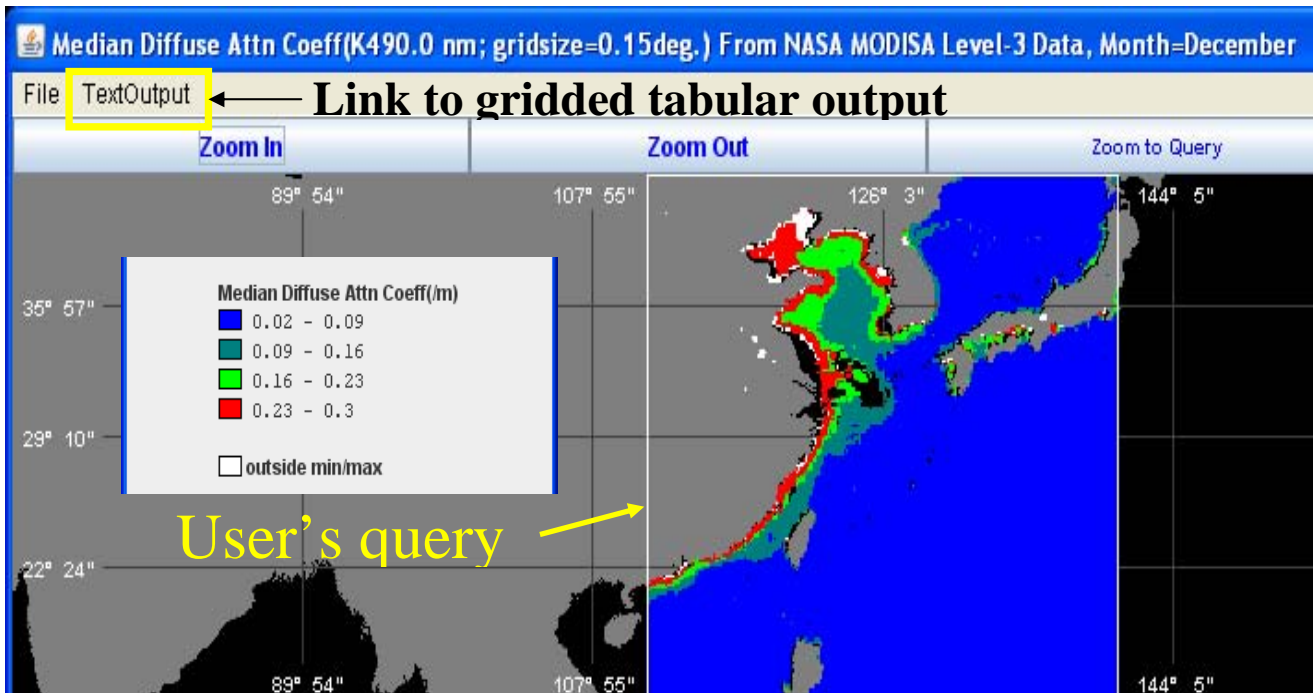
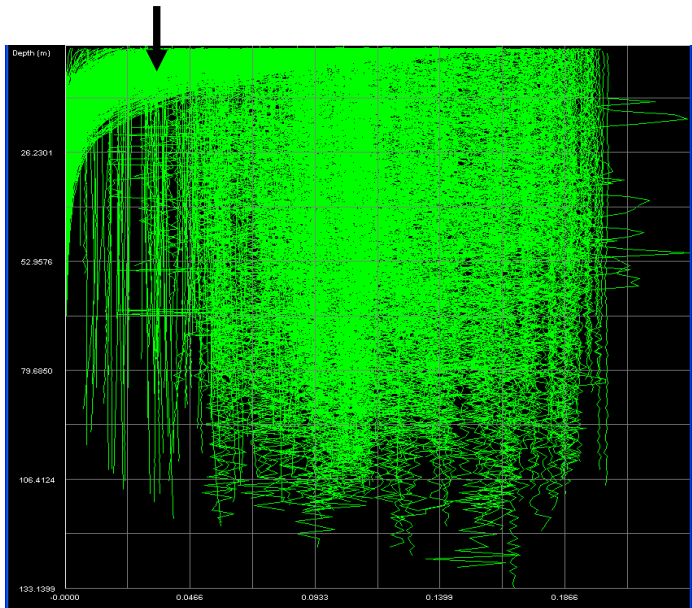


Figure 3. Example of New Statistical Map Display: Median December K490 in the Western Pacific Ocean. [Deep ocean regions have K490 < 0.09 /m while waters close to the coast and especially in the shallow Yellow Sea can have K490 values > 0.2 /m. Land is in gray and pixels with no data are in white.]

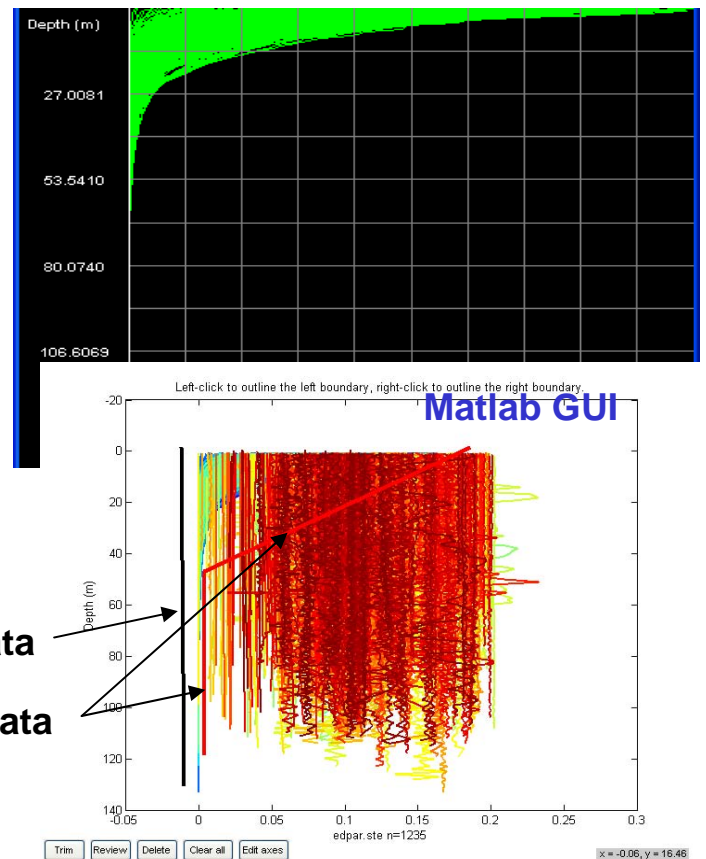
While processing/adding NASA's tens of thousands of bio-optical profiles to the database, Kevin Barrett, one of the project's three summer students, wrote several Matlab programs that are routinely used to quality screen and edit such raw data. As an example, Figure 4 shows an unedited set of downwelling irradiance profiles before and after the application of the "gedit" GUI that allows the user to outline the valid data domain using a few clicks of the mouse.

Empirical Algorithms: Sample profile data from the Korean Straits and from the Sea of Japan have been sent to Eric Rehm (University of Washington) to test the use of his radiative-transfer-based software for estimating $Ed(\lambda)$ and $Lu(\lambda)$ from multi-wavelength absorption, beam attenuation, and optical scattering depth profiles, and vice versa: estimating $a(\lambda)$, $c(\lambda)$, and $bb(\lambda)$ from $Ed(\lambda)$ and $Lu(\lambda)$. That work is still in a preliminary stage but one significant result to date is that it appears that the much simpler (and faster) Ecolight code provides results that are about the same as those produced using the much more complicated Hydrolight code. The main simplification in Ecolight is that it assumes azimuthal symmetry.

Valid data have exponential decay)



“EdPAR” profiles after processing
using the GUI



Left boundary to “good” data

Right boundary to “good” data

Figure 4. Example of Using New Quality Screening Software . [Raw data had many spurious profiles but after using the “gedit” GUI and a few clicks of the mouse to outline the regime for valid data, the bad data were all removed .]

RESULTS

Thousands of investigators from around the world have utilized the WOOD. The rate of usage has also dramatically increased from about 1200 unique IP addresses per year in 2001 to about 11,000 in 2004 and to about 20,000 since 2005. WOOD is routinely accessed by a wide variety of schools, colleges, universities, research institutes, and various DoD/US Government/State-Local Government agencies. Table 2 (shown on the next page) is an example of DoD/US Government-related “hits.”

As specific examples of US Navy use, the ONR Littoral Warfare Advanced Development (LWAD) Program used WOOD data extensively in planning for the LWAD 03-4 Sea Test in the East China Sea. In addition, the Environmental Support Systems Project within the SSBN Security Program used WOOD on seven different classified tasks during GFY 2008. WOOD has also been used to directly

support our ONR sponsor, Dr. Steve Ackleson. For example, in 2005 he requested an analysis of the ~ 30,000 K profiles in WOOD that exist on the continental shelf in order to determine the fraction of the world's continental shelves that are sufficiently clear to allow a bottom-mounted sensor to measure downwelling radiance.

Table 2. Partial List of DoD/US Government -related & University “hits” to WOOD from July 2007 to September 2008 (Note: many “hits” come from an obscure source such as “AT&T WorldNet Services” or “Verizon Internet Services Inc.”)

- | | |
|--|--|
| ➤Argonne National Laboratory | ➤Boston University |
| ➤National Aeronautics and Space Admin. | ➤Dalhousie University |
| ➤Naval Research Laboratory | ➤Duke University |
| ➤Naval Undersea Warfare Center | ➤Hawaii Pacific University |
| ➤Navy Network Information Center | ➤Johns Hopkins University APL |
| ➤U.S. Environmental Protection Agency | ➤Louisiana State University |
| | ➤Monterey Bay Aquarium Research Institute |
| | ➤Oregon State University |
| | ➤Stevens Institute of Technology |
| | ➤Texas A&M University |
| | ➤University of California, San Diego |
| | ➤University of Hawaii |
| | ➤University of Maine System |
| | ➤University of Maryland |
| | ➤University of New Brunswick |
| | ➤University of South Florida |
| | ➤University of Tennessee |
| | ➤University of Texas at Austin |
| | ➤University of Victoria |
| | ➤University of Washington |
| | ➤Virginia Institute of Marine Science (VIMS) |

IMPACT/APPLICATIONS

WOOD is regularly used at JHUAPL to support detectability and vulnerability studies for the US Navy. In addition, the empirical relations derived under this grant have been used to provide critical input parameters to US Navy-related vulnerability modeling efforts. Beyond these immediate applications at JHUAPL, data from WOOD have been used by other DoD facilities and by graduate students working on dissertations. Furthermore, by requiring all projects funded by ONR's Ocean Optics Program to submit their data to the WOOD, ONR is ensuring that these valuable data continue to be available for current and future investigators. It is estimated that the availability of a single location, uniform-format optics database has saved the US Navy many thousands of dollars in test planning and other naval applications. By providing the Navy and the research community with this resource, both types of users benefit from improved knowledge of the optical properties of the ocean. Access to historical optics data can also be useful for assessing newly acquired data. The two can be compared to see if the new results are atypical, and if so, one might go on to determine the cause (e.g.

unusual forcing conditions, influx of a different water mass, or perhaps even an instrument calibration problem).

TRANSITIONS

During the summer of 2008, the SSBN Security Program decided to add a classified version of WOOD to its suite of environmental databases that it maintains under the Environmental Support System (ESS) Project at JHUAPL. The entire contents of WOOD, along with its wide array of graphical displays and statistical outputs, have been copied to this clone of WOOD which is being augmented with various DoD-restricted and classified datasets.

RELATED PROJECTS

The project's Principal Investigator, Jeff Smart, is a Project Manager and Lead Scientist on several classified projects that regularly use WOOD data to plan US Navy field tests and to conduct vulnerability studies. Mr. Smart is also a member of the ONR Littoral Warfare Advanced Development (LWAD) project that conducts numerous at-sea tests, including tests involving optics in overseas areas of special interest to the US Navy. Via the LWAD project, the WOOD project has obtained important optical data in the East China Sea, the Philippine Sea, and the Yellow Sea. WOOD also provides LWAD with optics data for test planning purposes. The Applied Physics Laboratory works closely with the NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS) community in order to ensure that their bio-optical data are regularly added to the WOOD. In order to foster this relationship, US Navy permission was obtained to provide unclassified LWAD optics data (collected by JHU/APL scientists) to SeaBASS.

REFERENCES

¹ WOOD Website: <http://wood.jhuapl.edu>

² SeaSoar Website: <http://www.chelsea.co.uk/Vehicles%20SeaSoar.htm>

³ Rehm, E.; C. Mobley, D. Kiefer "IOP Retrieval Performance of a Hydro-Optical Analysis System (HOPAS)," Ocean Optics 2006, Montreal, Canada

⁴ SeaBASS website: <http://seabass.gsfc.nasa.gov>

⁵ Austin, R. W. and T. J. Petzold, "Spectral dependence of the diffuse attenuation coefficient of light in ocean waters," Optical Engineering, Vol 25 No. 3, pp 471479, Mar 1986.

PUBLICATIONS

Smart, J.H. and K.T. Barrett, "Data Thinning Algorithms for "Over-sampled" Multi-Parameter Profile Data," submitted to L & O Methods